Formation of vesicular bilayers in aqueous solutions containing mixtures of dialkyldimethylammonium bromides

Blandamer, M.J; Briggs, B.; Cullis, P.M.; Irlam, K.D.; Kirby, S.D.; Engberts, J.B.F.N.

Published in:
Journal of Molecular Liquids

DOI:
10.1016/S0167-7322(98)82006-0

Publication date:
1998

ELSEVIER

Journal of Molecular Liquids 75 (1998) 181–187

journal of MOLECULAR LIQUIDS

Formation of Vesicular Bilayers in Aqueous Solutions containing Mixtures of Dialkyldimethylammonium Bromides

Michael J. Blandamer,[a] Barbara Briggs,[a] Paul M. Cullis,[a] Keith D. Irlam,[a] Stuart D. Kirby[a] and Jan B. F. N. Engberts[b]

[a] Department of Chemistry, University of Leicester, LEICESTER LE1 7RH, U.K.
[b] Department of Organic & Molecular Inorganic Chemistry, University of Groningen, Nijenborgh 4, 9747 AG GRONINGEN, The Netherlands

DSC scans for vesicles in aqueous systems produced by mixtures of dihexadecyldimethylammonium (DHAB where R = $C_{16}H_{33}$ in $R_2N^+Me_2Br^-$) and dioctadecyldimethylammonium bromides (DOAB where R = $C_{18}H_{37}$ in $R_2N^+Me_2Br^-$) show for most mixtures two melting points corresponding to gel to liquid-crystal transitions which depend on the composition of the vesicular system. The gel to liquid-crystal transitions occur over a wider temperature range than for vesicular systems prepared using a single dialkyldimethylammonium surfactant. The resulting temperature-mole fraction diagram is similar to that observed for continuous solid solutions. The overall pattern shows that in a given solution two types of domains in the vesicular bilayer systems can co-exist having slightly different compositions and hence melting temperatures.

1. INTRODUCTION

Information concerning the properties of vesicles in aqueous systems is important in the task of understanding the properties of the more complicated natural lipid bilayer systems [1,2]. An interesting property is their melting temperature T_m characterising a gel to liquid-crystal transition [2]. This transition involves a change in the organisation of the dialkyl chains in vesicular bilayers formed by sodium dialkylphosphates and by dialkyldimethylammonium bromides. For systems prepared using dialkyl surfactants, the melting temperature T_m depends on the nature of the polar head group [3-5], the counterion [4] and the length of the dialkyl chains [4]. Where the aqueous vesicular system is prepared using an equimolar mixture of, for example, two sodium dialkylphosphates, two well-resolved extrema are observed in the DSC scans at two temperatures, each extremum being close to the melting temperatures T_m recorded for systems containing a single (sodium) dialkylphosphate [5]. This simple pattern is, however, only observed when the lengths of the alkyl chains differ by no more than two methylene groups [5]. With increase in the difference in alkyl chain lengths, the recorded plots become very complicated with several extrema across the temperature range.

PII S0167-7322(97) 00094-9

The relative simplicity of the DSC scans for equimolar mixtures of two (sodium) dialkylphosphates having similar chain lengths prompted the study reported below using vesicles formed by mixtures of dialkyldimethylammonium bromides, $R_2N^+Me_2Br^-$ where R = $C_{18}H_{37}$ (DOAB) and R = $C_{16}H_{33}$ (DHAB). We have recorded the DSC scans for aqueous solutions of mixtures spanning the complete mole fraction range. The results are summarised using a plot of melting temperatures T_m against mole fraction composition of the DHAB + DOAB mixture. The resulting plot closely resembles classic (*e.g.* textbook [6]) phase diagrams for solid solutions, simulated phase diagrams for a planar lipid bilayer [7] and recorded phase diagrams for mixtures of synthetic phospholipids, dimyristoylphosphatidylcholine and dipalmitoylphosphatidylcholine [8].

2. EXPERIMENTAL

2.1. Materials

The dialkyldimethylammonium surfactants, DOAB and DHAB, were obtained in the form of white powders from Aldrich Chemical Co. The vesicular aqueous solutions were prepared using the previously described 'hot-water' method [3-5] (see below).

2.2. Calorimetry

A MicroCal (USA) differential scanning microcalorimeter was used as previously described [3-5]. The volumes of sample and reference cells were approximately 1.2 cm^3. The reference cell was filled with water. The scans were recorded over the temperature range, 10 to 90 Celsius.

2.3. Protocol

An appropriate mass of each surfactant was added to a known volume of water to produce the required common concentration, 2×10^{-3} (monomer mol) dm^{-3}. The solution was heated to approximately 50 Celsius and held at that temperature for 30 minutes. After cooling to room temperature, a solution was placed in the sample cell and cooled to 5 Celsius. The DSC scan was recorded up to a maximum temperature of 90 Celsius. The sample was then allowed to cool in the calorimeter to 5 Celsius. The DSC scan was again recorded. In some experiments (see below) the aqueous vesicular system was held at 5 Celsius for periods of up to 11 hours before the scan was again recorded.

2.4. Analysis of DSC Scans

The DSC scans were characterised by one or more temperatures T_m corresponding to extrema in the recorded relative isobaric heat capacities. The recorded envelope formed by the dependence of this heat capacity on temperature was integrated to yield the calorimetric enthalpy expressed in terms of the total amount of dialkyldimethylammonium surfactant in the system.

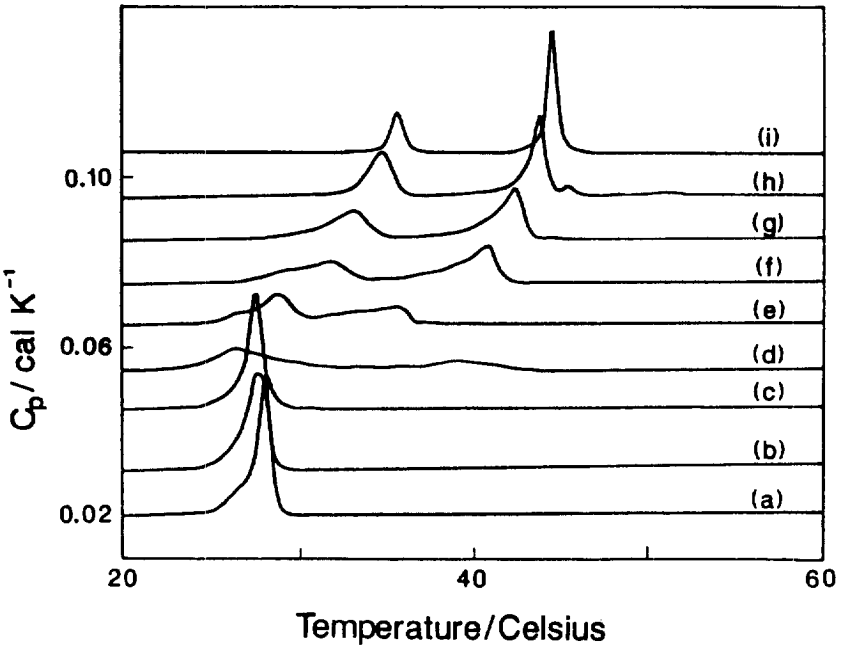

Figure 1. DSC scans for nine aqueous vesicular systems containing dialkyldimethylammonium bromides at constant overall concentration, 2.0×10^{-3} (monomer mol) dm^{-3}; the scans shown in this Figure were those recorded on the third scan after cooling to 5 Celsius; (a) DHAB (100%), (b) DHAB (95%) + DOAB (5%), (c) DHAB (85%) + DOAB (15%), (d) DHAB (75%) + DOAB (25%), (e) DHAB (50%) + DOAB (50%), (f) DHAB (25%) + DOAB (75%), (g) DHAB (15%) + DOAB (85%), (h) DHAB (5%) + DOAB (95%) and (i) DOAB (100%). The curves have been displaced on the heat capacity axis for clarity.

3. RESULTS

A summary of the results is given in Figure 1 which records a set of comparable scans for both the DOAB and DHAB aqueous systems together with the DSC scans for seven mixtures, all at the same overall concentration 2.0×10^{-3} (monomer mol) dm^{-3}.

For systems prepared using only DHAB, the characteristic melting temperaure is 28.1 Celsius. The scan was analysed to yield a calorimetric enthalpy of transition equal to 64.0 ± 0.5 kJ $(\text{monomer mol})^{-1}$. Further the analysis showed, using the previously described procedures [2-5], that the co-operative melting involves a domain or patch comprising 80 monomers. An electron micrograph of the DHAB solution confirmed that the system contained vesicles; Figure 2.

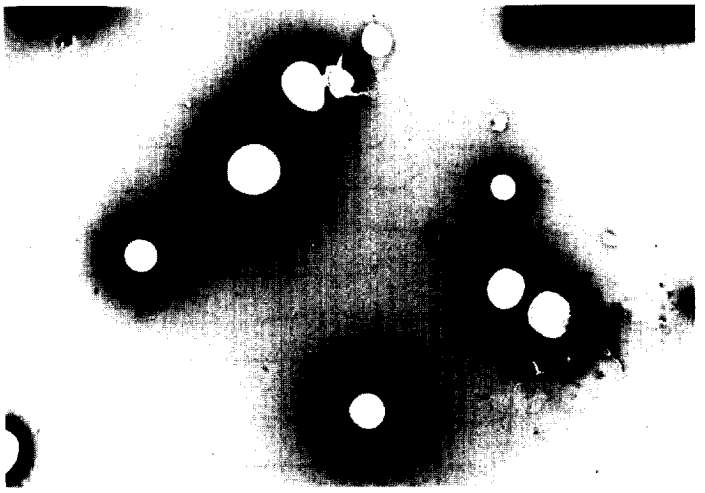

Figure 2. Electron micrograph of an aqueous DHAB vesicular system (2×10^{-3} mol dm^{-3}; magnification 8.5×10^3); for further details of the preparation, staining and microscope, see reference [4].

When DOAB (5%) was added to DHAB, the melting temperature decreased slightly to 27.6 Celsius, a trend which continued with increasing percentage of DOAB up to 25%. At the same time, the recorded scans became much more complicated. Nevertheless, for second scans recorded for freshly prepared solutions and all subsequent scans on the same solution, the scan patterns were reproducible. A typical set of scans is shown in Figure 3 for an aqueous system containing a mixture of DOAB (25%) and DHAB (75%) surfactants. The consistency of the scan patterns, numbered 2 to 5 confirms that the vesicular system has an intrinsic stability. Nevertheless, the scans in Figure 3 show features at higher temperatures than the main extremum near 27 Celsius. A noteworthy new feature is evidence of an extremum near 40 Celsius. With increase in percentage of DOAB in the mixture of surfactants used to prepare a vesicular system so the extremum near 30 Celsius shifted to higher temperatures and the new feature above 40 Celsius became more clearly defined, also moving to higher temperature with increase in the percentage of DOAB. The scans for these systems were also reproducible through several heat-cool-heat-cool ..... cycles; Figure 4. The DSC scans for systems containing only DOAB confirmed the previously reported results [5].

The results of the DSC scans can be summarised in several ways. Possibly the most significant summary is a plot showing the interdependences of the temperatures corresponding to the main features in the scans and the percentage composition of the vesicular solutions; Figure 5. Although the key extrema are difficult to identify for all scans, the pattern which emerges has many similarities with phase diagrams for completely miscible solid solutions formed by two solids (*cf.* Figures in references 6).

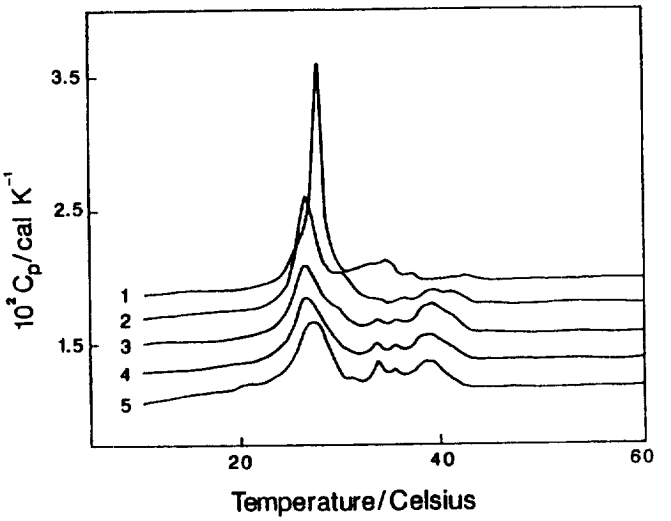

Figure 3. Recorded DSC scans for aqueous vesicular systems containing DHAB [1.5×10^{-3} (monomer mol)$^{-1}$] and DOAB [0.5×10^{-3} (monomer mol)$^{-1}$]. Scan 1 was recorded immediately after preparation of the solutions using the 'hot-water' method (see Experimental). Scans 2-4 were recorded after the solutions had cooled in the calorimeter from 90 Celsius. Scan 5 was recorded after the system had been held at 5 Celsius in the scanning calorimeter sample cell for 11 hours.

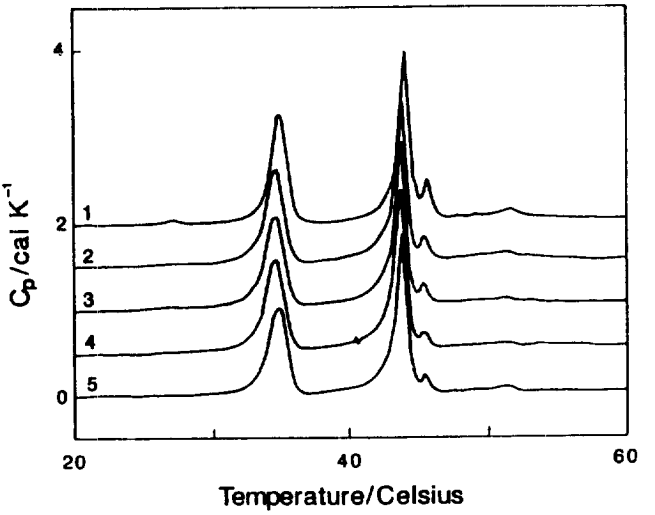

Figure 4. Repeat DSC scans for aqueous vesicular systems containing DOAB [1.9×10^{-4} (monomer mol) dm^{-3}] and DHAB [0.1×10^{-4} (monomer mol) dm^{-3}]. Scan number 5 was recorded 11 hours after scan number 4 had been recorded.

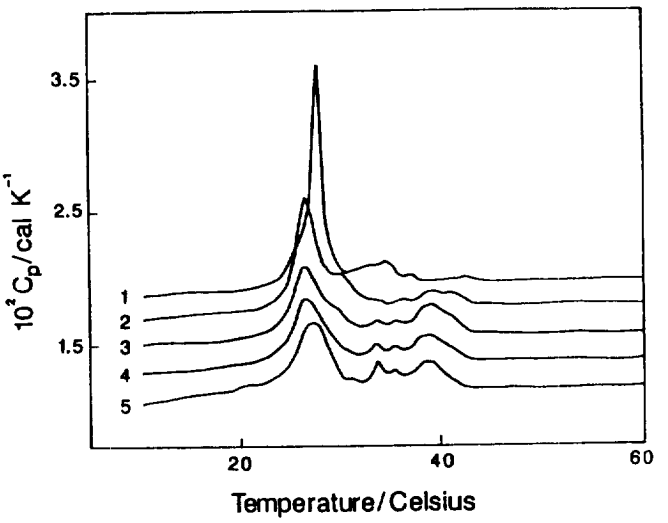

Figure 3. Recorded DSC scans for aqueous vesicular systems containing DHAB [1.5×10^{-3} (monomer mol)$^{-1}$] and DOAB [0.5×10^{-3} (monomer mol)$^{-1}$]. Scan 1 was recorded immediately after preparation of the solutions using the 'hot-water' method (see Experimental). Scans 2-4 were recorded after the solutions had cooled in the calorimeter from 90 Celsius. Scan 5 was recorded after the system had been held at 5 Celsius in the scanning calorimeter sample cell for 11 hours.

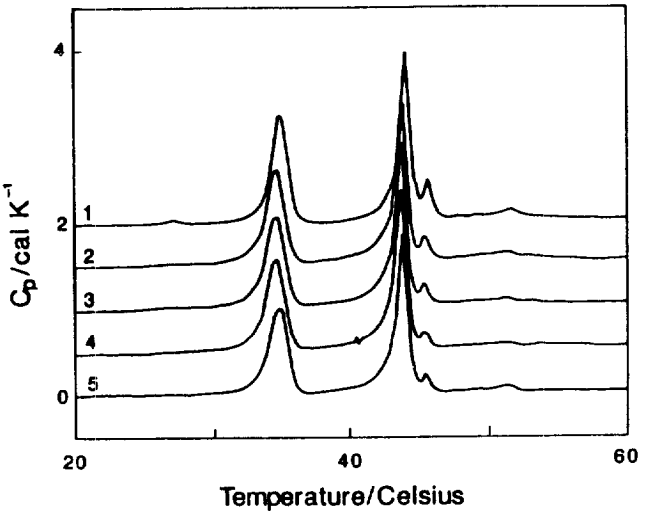

Figure 4. Repeat DSC scans for aqueous vesicular systems containing DOAB [1.9×10^{-4} (monomer mol) dm^{-3}] and DHAB [0.1×10^{-4} (monomer mol) dm^{-3}]. Scan number 5 was recorded 11 hours after scan number 4 had been recorded.

DHAB and DOAB indicate complexity in the phase diagrams for these systems. For a DOAB + DHAB vesicular system having a given overall mole fraction composition, there are domains (patches [2]) in the bilayers which differ in composition and hence in the temperatures characterising gel-to-liquid crystal transitions. The difference in composition for this system is small because the chain lengths of the alkyl groups are similar. In these terms there is a stereochemical factor controlling how the dialkyl chains pack together in the bilayers. [The co-existence of domains having different compositions is observed [9] in related systems where a phospholipid bilayer has cholesterol-rich and cholesterol-poor domains.]

We suspect that this explanation might not be satisfactory where the alkyl chain lengths are markedly different. In the latter case, as noted previously [2], the scan patterns show no clear pattern. As more information about these systems emerges, we are struck by the enormous diversity in the properties of these synthetic bilayer systems and by the enormous challenge these systems present.

REFERENCES

1. J.-H. Fuhrhop and J. Köning, *Membranes and Molecular Assemblies: The Synthetic Approach*, Royal Society of Chemistry, 1994.
2. M. J. Blandamer, B. Briggs, P. M. Cullis and J. B. F. N. Engberts, *Chem. Soc. Revs.*, 24 (1995) 251.
3. M. J. Blandamer, B. Briggs, P. M. Cullis, J. A. Green, M. Waters, L. G. Soldi, J. B. F. N. Engberts and D. Hoekstra, *J. Chem. Soc., Faraday Trans.*, 88 (1992), 3431.
4. M. J. Blandamer, B. Briggs, P. M. Cullis, J. B. F. N. Engberts, A. Wagenaar, E. Smits, D. Hoekstra and A. Kacperska, *Langmuir*, 10 (1994) 3507.
5. M. J. Blandamer, B. Briggs, P. M. Cullis, J. B. F. N. Engberts, A. Wagenaar, E. Smits, D. Hoekstra and A. Kacperska, *J. Chem. Soc., Faraday Trans.*, 90 (1994), 2703; 2709.
6. N. K. Adam, *Physical Chemistry*, Oxford, 1956, page 343.
7. O. G. Mouritsen, B. Dammann, H. C. Fogedby, J. H. Ipsen, C. Jeppesen, K. Jørgensen, J. Risbo, M. C. Sabra, M. M. Sperotto and M. J. Zuckermann, *Biophysical Chemistry*, 55 (1995) 55.
8. S. Mabrey and J. M. Sturtevant, *Proc. Natl. Acad. Sci. USA*, 73 (1976) 3862.
9. T. P. W. McMullen and R. N. McElhaney, *Current Opinion Coll. Int. Sci.*, 1 (1996) 83.